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Neurobiology of Aging 28 (2007) 1623–1627

NEUROBIOLOGY OF AGING

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Brief communication

# Age effects on gray matter volume and attentional performance in Zen meditation

Giuseppe Pagnoni *, Milos Cekic

*Department of Psychiatry and Behavioral Sciences, Emory University, 101 Woodruff Circle, Suite 4000, Atlanta, GA 30322, USA*

Received 7 March 2007; received in revised form 25 April 2007; accepted 5 June 2007
Available online 25 July 2007

**Abstract**

Zen meditation, a Buddhist practice centered on attentional and postural self-regulation, has been speculated to bring about beneficial long-term effects for the individual, ranging from stress reduction to improvement of cognitive function. In this study, we examined how the regular practice of meditation may affect the normal age-related decline of cerebral gray matter volume and attentional performance observed in healthy individuals. Voxel-based morphometry for MRI anatomical brain images and a computerized sustained attention task were employed in 13 regular practitioners of Zen meditation and 13 matched controls. While control subjects displayed the expected negative correlation of both gray matter volume and attentional performance with age, meditators did not show a significant correlation of either measure with age. The effect of meditation on gray matter volume was most prominent in the putamen, a structure strongly implicated in attentional processing. These findings suggest that the regular practice of meditation may have neuroprotective effects and reduce the cognitive decline associated with normal aging.


*Keywords:* Meditation; Aging; VBM; Gray matter; Attention; Training; Plasticity

## 1. Introduction

Buddhist meditative practices have received considerable attention recently (Barinaga, 2003; Knight, 2004), for their potential phenomenological and epistemological contributions to cognitive science (Varela et al., 1991) and as a context in which to investigate neural plasticity related to mental practice (Lutz et al., 2004). The latter point is particularly relevant here: not unlike learning a second language or a musical instrument, meditation traditionally requires a long-term commitment to daily practice and therefore has the potential to induce changes in neural function and structure. While meditative practices can vary greatly, even within the Buddhist tradition itself, a core characteristic is the importance assigned to attentional and postural self-regulation, indicating the engagement of voluntary selection and inhibition processes common to many training situations. Zen meditation, in particular, is performed by sitting cross-legged (in the "lotus" or "half-lotus" position) and trying to maintain throughout the session a straight posture, a normal breathing pattern, and a mental attitude of openness to one's own mental processes while recognizing the occurrences of episodes of mind-wandering and distraction.

The recent development of imaging techniques has allowed researchers to observe learning-related morphological brain changes in domains as diverse as spatial navigation (Maguire et al., 2000), music (Gaser and Schlaug, 2003), language (Mechelli et al., 2004), and juggling (Draganski et al., 2004). While structural effects of training, typically observed as regional increases in gray matter volume or thickness of the cortical sheet, represent one facet of normal brain plasticity, an equally important and counteracting factor is age. Gray matter volume and cortical thickness have been shown to decrease starting at or immediately after adolescence (Good et al., 2001; Sowell et al., 2003), a loss that is partially echoed by some aspects of cognitive function, particularly in the attentional and executive domains (Chao

* Corresponding author. Tel.: +1 404 712 9582; fax: +1 404 727 3233.
*E-mail address:* gpagnon@emory.edu (G. Pagnoni).

0197-4580/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.neurobiolaging.2007.06.008

and Knight, 1997). In the present study, we used voxel-based morphometry (VBM) (Ashburner and Friston, 2000) and a computerized neuropsychological test to examine the putative effect of regular meditative practice on the age-related decline in gray matter volume and attentional performance observed in healthy subjects. Given the cross-sectional design of the study, the use of terms such as “decline” or “rate of change” should be generally interpreted here as between-subjects inferences rather than directly observed longitudinal effects.

## 2. Methods

Thirteen Zen meditators (MEDT) with more than 3 years of daily practice were recruited from the local community and meditation centers, along with 13 control subjects (CTRL) who never practiced meditation. The groups were matched by sex (CTRL = 10 M; MEDT = 10 M), age (mean ± S.D.: MEDT, 37.2 ± 6.9 years; CTRL, 35.5 ± 5.7 years; two-tailed two-sample *t*-test: $p = 0.50$), and education level (mean ± S.D.: MEDT, 17.8 ± 2.4 years; CTRL, 17.8 ± 1.7 years; $p = 0.93$). All participants were native speakers of English (one control was bilingual) and right-handed, except one meditator who was ambidextrous. Subjects gave written informed consent for a protocol approved by the Emory University Institutional Review Board.

Individual capacity for sustained attention was assessed via a computerized task of rapid visual information processing (RVIP) from the CANTAB battery (Sahakian and Owen, 1992). The task requires the continuous monitoring of a stream of fast occurring digits in the center of a computer screen for the occurrence of three specific target sequences. Performance is computed in terms of reaction times (RT) and $A'$, a nonparametric sensitivity index from signal detection theory, which rates the ability to detect targets on a scale from 0 to 1 (1 represents perfect performance) based on the number of hits and false alarms (Green and Swets, 1966). Since each subject performed the task twice, as part of a different section of the study examining the relationship of autonomic function during meditation and attentional performance (to be discussed elsewhere), the average of the measurements at the two time points was selected as an index of the individual capacity for sustained attention.

A high-resolution T1-weighted whole-brain image was collected for every subject on a 3T Siemens Trio MRI scanner (MPRAGE, TR/TE/TI = 2300/3.93/1100 ms, NEX = 1, flip angle = 8°, voxel size = 1 mm × 1 mm × 1 mm) and individual gray matter tissue probability maps (TPMs) were computed, spatially warped to standard MNI space (with intensity modulation to preserve the total amount of gray matter) and smoothed with a 12 mm Gaussian kernel, using the software SPM5 (http://fil.ion.ucl.ac.uk/spm/software/spm5) and the VBM toolbox (http://dbm.neuro.uni-jena.de/vbm). The image of one subject in the MEDT group was corrupted by an MRI artifact, and was therefore removed from subsequent VBM and correlation analyses (the subject's RVIP scores were retained for the analyses of behavioral data). For each individual, the total probable gray matter volume was assessed by integrating the intensity of the gray matter TPM across the whole-brain, and a cranium scaling factor was computed with the routine *sienax* from the imaging software package FSL (Smith et al., 2004) as a covariate accounting for the effect of head size in the VBM group analysis (Fein et al., 2004). A linear model with Group, Age, and Age × Group as predictors, and cranium scaling factor and gender as confounds, was estimated as a statistical parametric mapping (SPM) procedure performed voxel-wise on the gray matter TPMs. The resulting map for the effect of interest Group × Age was thresholded at a single-voxel significance level of $p < 0.001$ and a cluster size of $k > 1000$.

The individual scores on the RVIP task ($A'$ and RT) were entered into a group-wise Pearson's correlation analysis with age. A linear model (ANCOVA) with Age, Group, and Age × Group as regressors was also estimated for $A'$ and RT. Similar analyses (group-wise Pearson's correlation with age and ANCOVA) were performed for the total gray matter volume and local gray matter volume in a region of interest (ROI) identified by the SPM procedure, after correcting both measures for the cranium scaling factor and gender.

## 3. Results

The adjusted total gray matter volume showed a marginally significant negative correlation with age in the control group (Pearson's $r = -0.54$, $p = 0.056$) that was not apparent in the meditators group ($r = 0.006$, $p = 0.83$) (Fig. 1, top-left). The ANCOVA revealed an Age × Group interaction for total gray matter volume at a trend significance level ($t(19) = 1.82$, $p = 0.08$), with an estimated rate of change of −4.7 ml/year for the control group versus +1.8 ml/year for the meditators group. Notably, the capacity for sustained attention as indexed by performance scores in the RVIP task exhibited a very similar pattern (Fig. 1, right-side): the group-wise Pearson's correlation analyses showed that while target sensitivity and quickness to respond decreased with age in control subjects ($A'$: $r = -0.72$, $p = 0.006$; RT: $r = 0.82$, $p = 0.0006$), they remained virtually constant in meditators ($A'$: $r = -0.09$, $p = 0.78$; RT: $r = -0.26$, $p = 0.39$). The ANCOVA for $A'$ showed a significant effect of Age ($F(1,22) = 4.87$, $p = 0.038$), and a trend for significance for the Group × Age interaction ($F(1,22) = 3.13$, $p = 0.091$); the effect of Group was not significant ($F(1,22) = 1.29$, $p = 0.27$). The ANCOVA for RT showed significant effects of Age ($F(1,22) = 5.14$, $p = 0.034$) and Group × Age ($F(1,22) = 19.9$, $p = 0.0016$) but not Group ($F(1,22) = 2.31$, $p = 0.14$). In addition, the whole-brain SPM analysis identified a single significant cluster for the Group × Age interaction in the left putamen (Fig. 2, left). The individual values for the adjusted gray matter volume in the ROI identified by this cluster were extracted and entered into a group-wise Pearson's correla-

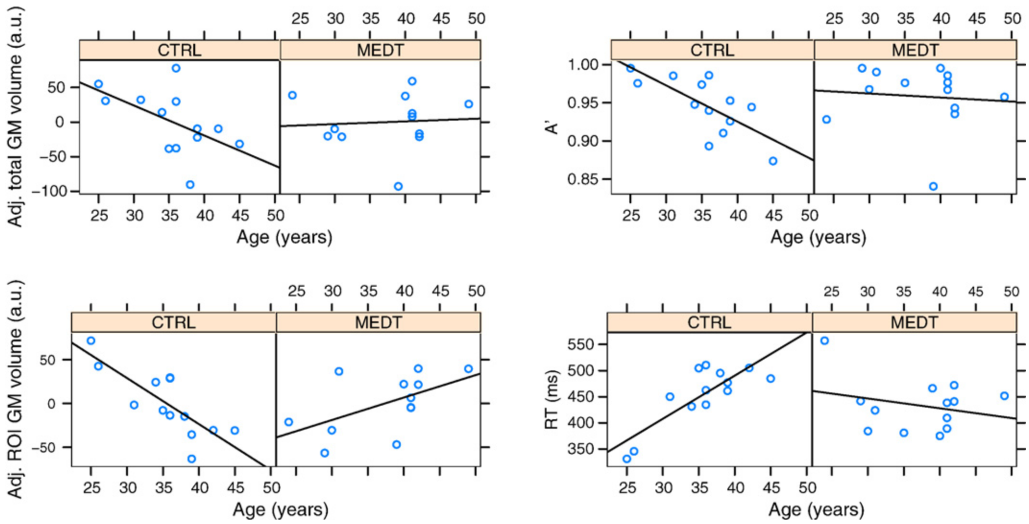


Fig. 1. Age-related changes in controls (CTRL) and meditators (MEDT). The left column shows total gray matter volume and regional gray matter volume in the left putamen cluster (values are adjusted for head size and gender and are therefore reported as a.u.). The right column reports the performance in the sustained attention task in terms of target sensitivity $A'$ (where $A'=1$ represents perfect score) and reaction time RT.

tion analysis with age, for comparison with the total gray matter results. The ROI adjusted gray matter values were negatively correlated with age in the control group ($r=-0.80$, $p=0.0011$), but positively in the meditators group, albeit at a trend level of significance ($r=0.55$, $p=0.063$) (Fig. 1, bottom-left).

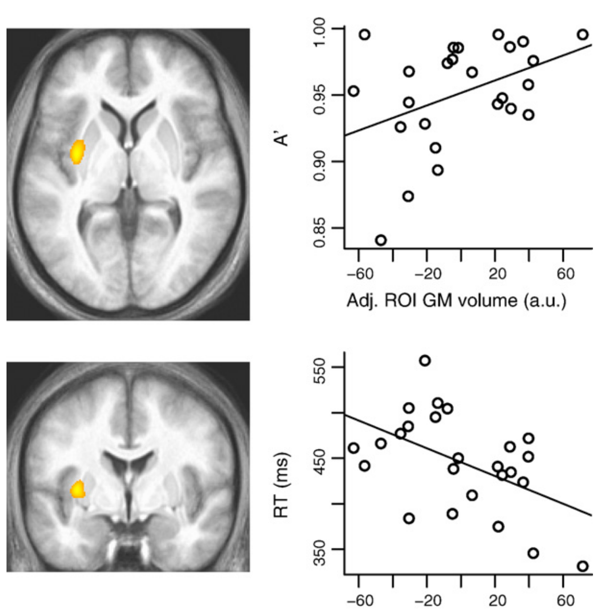


Fig. 2. Left side: region in the left putamen displaying a significant Age × Group interaction for gray matter volume at a combined threshold of $p=0.001$ (uncorrected) and cluster size $k>1000$ voxels (1203 voxels, peak $t$-value = 5.45 at MNI coordinates −33, −5, 2); the statistical map is overlaid on the average of the individual MNI-normalized T1-weighted images in axial ($z=2$ mm) and coronal ($y=-3$ mm) views. Right-side: between-subjects correlation of the adjusted gray matter volume in the putamen ROI and the performance scores in the RVIP task ($A'$ and RT).

In order to better understand the relationship between attentional performance and VBM results, we pooled MEDT and CTRL subjects together and performed a Pearson's correlation analysis between the individual scores on the RVIP task (RT and $A'$) and the gender- and head size-adjusted VBM values for both the total gray matter volume and the regional gray matter volume in the left putamen cluster identified by the SPM analysis. Total gray matter volume correlated significantly with target sensitivity ($r=0.60$, $p=0.0014$) and with reaction time ($r=-0.46$, $p=0.021$). Gray matter volume in the putamen cluster also correlated significantly both with target sensitivity ($r=0.41$, $p=0.042$) and reaction time ($r=-0.50$, $p=0.011$) (Fig. 2, right).

## 4. Discussion

We observed a difference in the age-related decline rate of cerebral gray matter volume in the putamen between regular Zen meditators and control subjects, with total cerebral gray matter volume displaying a trend of significance for the same effect. These findings were complemented by a similar pattern in the capacity for sustained attention, a cognitive process that occupies a central position in the meditative exercise. While an observed difference in anatomical structure correlating with an individual ability can be generally interpreted as either an innate neural predisposition to that ability or a learning-dependent alteration, there is strong evidence in humans that intensive practice of a task for a period of only a few months can in fact induce anatomical plasticity detectable with VBM (Draganski et al., 2004; Draganski et al., 2006). The present results are also in line with a previous report of increased cortical thickness associated with the practice of insight meditation (Lazar et al., 2005). While age-related decline of gray matter was not the focus of their work and the cortical thickness methodology they employed does not apply to subcortical structures like the basal ganglia (Fischl and Dale, 2000), Lazar and colleagues did report a difference between meditators and controls in the correlation of age and cortical thickness of prefrontal areas. Notably, a similar effect for gray matter volume in the prefrontal cortex was also observed in our data when the statistical threshold for the VBM analysis was lowered.

Albeit the cross-sectional design of the present study cannot rule out the possibility of a selection bias (i.e., subjects less prone to cognitive and neural aging could also be more inclined to practice meditation or could differ from controls on some hidden variable, such as diet), it is worthwhile to consider the mechanisms that could underlie a potential neuroprotective effect of meditation. Zen meditation is a task that is likely to influence brain function at several levels, from autonomic and hormonal regulation to emotional and executive processes (Austin, 1998). The finding of a reduced rate of decline with age of both global (albeit at a trend level of significance) and regional gray matter volume in meditators may in fact indicate the involvement of multiple mechanisms of neuroprotection. Potential causal factors for the observed VBM global changes include autonomically mediated vascular effects, modulation of hypothalamic–pituitary–adrenal (HPA) axis activity (McEwen, 2000), and CNS-mediated influence on immune function (Tracey, 2002). Although the evidence is quite sparse, effect of meditation on stress reduction (Kabat-Zinn et al., 1992), autonomic regulation (Corby et al., 1978; Cysarz and Bussing, 2005; Kubota et al., 2001), and immune activity (Davidson et al., 2003) have all been previously reported in the literature.

The observed regional effect in the putamen, on the other hand, may be more specifically related to the cognitive processes engaged by meditation, such as the conscious regulation of attention and posture. The basal ganglia's corpus striatum, which includes the putamen, is a predominantly dopaminergic structure that beyond its classical role in motor control and learning is also implicated in cognitive flexibility and attentional processing (Nieoullon, 2002). Notably, the putamen has been strongly linked to attention-deficit hyperactivity disorder (ADHD) (Konrad et al., 2006; Teicher et al., 2000), which is striking given that the attentional and postural control embedded in Zen meditation can be viewed as mirroring in reverse the characteristic deficits of ADHD. It is not unreasonable to hypothesize that consistent meditative practice might partially counteract the normal age-related shrinkage of the striatum observed in healthy subjects (Raz et al., 2003), as well as the reduction in dopaminergic activity associated with cognitive senescence (Volkow et al., 1998). Long-term effects of meditative practice on gamma-band EEG synchronization, which is thought to reflect attentional processes (Fries et al., 2001), has also been recently reported (Lutz et al., 2004).

It has been argued that the study of the "atypical" attentional processes mobilized by meditation and their long-term effects could prove useful in clinical settings and for attention research in general (Raz and Buhle, 2006). Attention and working memory training programs have indeed been shown to reduce behavioral and associated neurophysiological changes in healthy children (Rueda et al., 2005), children diagnosed with ADHD (Klingberg et al., 2005), and patients with spatial neglect (Robertson et al., 1995; Thimm et al., 2006). The present findings, despite the limitations of small sample size and cross-sectional design, can provide a useful contribution to this growing area of research.

## Conflict of interest

The authors declare that they have no conflict of interest, financial or otherwise, related to the present work.

## Acknowledgments

The study was supported by the Emory Center for Research on Complementary and Alternative Medicine in Neurodegenerative Diseases (National Institute of Health Grant P30-AT00609).

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